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OPERATION OF AUTOMATIC LEVEL REGULATORS FOR EQUIPMENT OF THE 12-CHANNEL V-12 SYSTEM

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The article discusses the operation of automatic level regulators for transmission over long aerial communication lines, carrier-channelized by the 12-channel V-12 system apparatus. An explanation is given of the effect of various factors on the restoration of the transmission level whenever it deviates from the norm and on the quality of the communication channels. The principal methods for reducing the undesirable phenomena of "overregulation" are explained; these methods should be taken into account in the construction of automatic level regulation units and in the operation of the apparatus.

In long aerial communication lines, carrier-channelized by the 12-channel V-12 system and having a large number of electromechanical level regulators, the process of restoration of the normal transmission level whenever this level changes at one of the repeater sections, is quite complicated. The above process is affected not only by the magnitude of the change in level and by the number of regulators, but also by the speed of operation of the regulators, the value of the sensitivity threshold of the polarized relay that actuates the regulators, the time required to operate the system of ARU [Avtomaticheskaya regulirovka urovnya -- automatic level regulation] installation, the time to switch over the regulated drive in case the direction of regulation is reversed, and certain other factors which must be taken into account in the construction of ARU installations and under operating conditions.

To gain a general idea on how the level is restored at the end of an interurban line whenever the level is disturbed at one of the repeater sections, and to explain the principal laws governing this process, let us first examine an aerial line equipped with 6 ideal static level regulators, the regulation speed of which varies as an exponential curve. For simplicity we admit here a certain arbitrariness: actually, the automatic regulators in the V-12 system have a variable regulation speed, which increases along a broken line as the regulator scale changes from the 0 to the 100 position, owing to the switching of artificial-line networks having unequal attenuation slopes. In addition, we assume arbitrarily that the sensitivity threshold of the regulators is 0 and that there are no settling processes in the amplifiers or filters.

The equivalent circuit of such a line is shown in Figure 1. The time constants T of all the regulators are equal

$$T = R_1C_1 = R_2C_2 = \dots R_6C_6 ,$$

where R and C are the equivalent active and capacitive components of the regulators respectively.

If the reception level at the input of the first amplifier and of the static regulator is changed by an amount ΔP_0, the deviation of the level at the output of the same amplifier will vary exponentially

$$P_1(t) = \Delta P_0 \cdot e^{-\frac{t}{T}}$$

where t is the time elapsed from the instant that the given regulator started regulating the level.

The level fluctuations at the output of the second and subsequent amplifiers can be determined by using an equation that is suitable for the investigation of a voltage produced by an electromotive force of any form

$$\Delta P(t) = \frac{d}{dt} \int_0^t u(\tau) A(t - \tau) d\tau,$$

where $u(\tau)$ is the function of the applied voltage, $A(t - \tau) = e^{-\frac{t-\tau}{T}}$ is the admittance that is assuming steady state.

The results of the calculations made on the basis of the above equations are shown in the form of curves in Figure 2. In this graph the abscissa represents the ratio of the duration of the "overregulation" t in seconds to the time constant T of the regulator, while the ordinate axis represents the ratio of the deviation of the level at the end of the line ΔP to the ratio of the initial level disturbance ΔP_0. (Hereinafter we shall mean by "overregulation" a deviation in the transmission level in a direction opposite to its initial deviation.)

On the basis of these curves it is possible to draw the following conclusions: (1) the level assumes steady state with considerable attenuation; (2) if many level regulators are used, a considerable amount of overregulation occurs during the time of level regulation, and the amplitude of the overshoot of the first half wave increases with the number of amplifiers connected to the line; (3) as the number of amplifiers increases, the duration of the overregulation in the first half wave of the oscillation of level decreases; (4) if all regulators have equal time constants the amplitude of the overregulation depends only on the number of regulators.

Restoration Process of the Level at the End of the Line Produced by Operation of the Level Regulators of the V-12 Apparatus

The automatic level regulators of the V-12 apparatus are astatic regulators the speed of operation of which is constant at the individual portions of the scale and is independent of the speed and magnitude of the level oscillations at their input. The sensitivity threshold of these regulators is ± 0.05 nep; the speed of operation of the ARU, owing to the backlash between the shaft of the synchronous electric motor and the rotor shaft of the variable capacitors of the artificial lines, is approximately 1--2 seconds; the time required to switch the drive when changing the direction of regulation does not exceed 2 seconds. Let us examine separately the effects of the indicated factors on the process of restoring a disturbed level in an aerial line.

Effect of Time Required to Switch the Drive when the Regulation Changes Direction

If the line contains n amplifiers equipped with ARU devices, and the attenuation of the control frequency current has changed in one of the repeater sections, all the following regulators except for the first one, at which the level has become disturbed, first regulate the level to 0.05 nep. Next, owing to the operation of the preceding regulators, all the active regulators continue to raise the level beyond the initial value, and this is followed by regulation in the opposite direction. As a result, the level at the output of each regulators will vary with a speed $(n - 2)\nu$, where ν is the speed of operation of the regulator.

Prior to the time that the changing direction of regulation causes the drive to switch over, i.e., during the time $\tau = 2$ seconds, the level regulator will not operate. For example, whenever a level of 0.05 nep is established at the output of an amplifier, the second regulator will start changing the level in the opposite direction only after a lapse of 2 seconds. Consequently, during this time interval, there will be an overregulation with an amplitude $\nu\tau$ at the output of the second regulator. Overregulation will also occur in the third amplifier, also owing to the time lapse involved in switching the drive over with changing direction of regulation. The value of the amplitude of the total overregulation at the output of the third amplifier, disregarding the sensitivity threshold of the ARU, will be:

$$\Delta P_3 = \nu\tau + \nu(t_2 - t_3).$$

It can be shown for example, that in the case of the odd regulators the overregulation amplitude of the first wave of level oscillation in the trunk line is given by the following equation

$$\Delta P_n = \Delta P_0 \sum_{k=1}^{k=\frac{n-1}{2}} \frac{n+1-2k}{[(n+1)-(k-1)]\,(n+1-k)} + \\ + \frac{n-1}{2}\nu\tau$$

where n is the number of regulated amplifiers and k is the number of the term of the sum.

It follows from the equation that an increase in the time τ , required to switch the drive over whenever the regulation direction change is increased, as well as an increase in the speed of regulation, both cause an increase in the amplitude of the overregulation. On the other hand, the duration of the regulation process decreases, something that is not seen directly from the equation, but can be proved graphically. In addition, the increase in the amplitude of the overregulation depends also on the extent to which the level becomes disturbed.

The time τ' required for the regulators to operate, owing to the backlash between the shaft of the electric motor and the shaft of the capacitor rotor, amounts to 1 -- 2 seconds in the V-12 system. Such slow operation protects the ARU against overregulation during the short-time level oscillations. As in the case of the time required to switch over the direction of regulation, this operating time increases the amplitude of the overregulation in accordance with the following equation, which was derived for even regulators:

$$\Delta P_n - \Delta P_0 \sum_{k=1}^{k=\frac{n}{2}} \frac{n-2k}{[n-(k-1)](n-k)} + \frac{nv}{2}\tau'.$$

Effect of the Threshold Sensitivity of the ARU Installations

The threshold sensitivity of the polarized relays employed in the ARU installations of the V-12 apparatus is ± 0.05 nep. This means that whenever the level of the control-frequency current deviates within ± 0.05 nep from the nominal value, the ARU system does not operate, and with this the residual attenuation of the channels also remains within the norm. Such a sensitivity threshold insures stable operation of the regulation, although it does increase the amplitude of the first half wave of the overregulation. However, increasing the sensitivity threshold of the ARU installations and thereby reducing the duration of the regulation, may lead to large fluctuations in the residual attenuation, particularly in long trunk lines having a large number of regulators.

Dynamics of the Process of Restoring a Varying Transmission Level

Let us examine in detail the dynamics of the process of restoring a level whenever the level is changed suddenly in one of the sections of the line carrier-channelized by the V-12 apparatus and employing ARU installations that have the following parameters: $\Delta = \pm 0.05$ nep, $\tau' = 1$ second, $\tau = 2$ seconds, $\nu = 0.062$ nep/minute $\approx$ 0.001 nep/second.

If the transmission level changes suddenly in one of the repeater sections by 0.5 nep, all the following regulators, except for the first one, in whose section the level has changed, will go into operation. The level of the control-frequency current at the output of the first amplifier should reach its nominal value within a time

$$t = \frac{\Delta P_0}{\nu} = \frac{0.5}{0.001} = 500 \text{ seconds}$$

However, owing to the initial error of the regulator, the restored level will differ from the nominal level by $\Delta = 0.05$ nep, and the duration of the regulator operation will be (see curve IV in Figure 3)

$$t_1' = \frac{0.5 - 0.05}{0.001} = 450 \text{ seconds}$$

Thus, the regulation will terminate when the level at the output of the first amplifier becomes 0.05 nep.

The level at the output of the second regulator (curve 2V) will be restored to its initial value, minus the error Δ, at twice the speed, owing to the operation of the first and second regulators, and within a time interval of

$$t_2' = \frac{\Delta P_0 - \Delta}{2\nu} = \frac{0.5 - 0,05}{2 \cdot 0.001} = 225 \text{ seconds}$$

the second regulator will stop. In the meantime the first regulator still continues to operate, increasing the level at the output of the second regulator. Therefore, after a time interval required to exceed the level of the control frequency current and to switch over the second regulator to operate in the opposite direction, i.e.,

$$t_{\Delta 1} = \frac{2\Delta}{\rho} + \tau + \tau' = \frac{2 \cdot 0{,}05}{0{,}001} + 1 + 2 = 103 \text{ seconds}$$

has elapsed, the second regulator will again go into operation, but already in the opposite direction. As a result the level at the output of the second regulator will be constant for 122 seconds (until the first regulator stops operating: 450 – 225 – 103 = = 122 seconds).

Next, within a period of time $\tau' + \tau = 3$ seconds, the level drops to $\Delta = +\ 0.05$ nep, and the regulating process stops. The second regulator will be in operation for an overall of 350 seconds, as can be easily computed graphically.

We shall not examine the subsequent regulators, for their operation is analogous. The characteristic data for the dynamics of the regulation process are given in the table.

Number of Regulator	$\frac{\Delta P_n}{\Delta P_0}$ 1)	Duration of Regulator Operation, seconds 1)
1	0/0	500/450
2	0/0,104	500/350
3	0,160/0,160	335/303
4	0,160/0,228	335/249
5	0,230/0,257	320/220
6	0,230/0,296	302/202

1) Numerator -- without taking the values of Δ, τ, and τ' into account;

Denominator -- taking these quantities into account.

It can be seen from this table and from Figure 3 that if the regulators have a sensitivity threshold Δ and a lag τ and τ', the amplitudes of the overregulations are somewhat higher compared with regulators in which $\Delta = 0$; $\tau = 0$; and $\tau' = 0$. However, the length of operation of each regulator is considerably decreased, and consequently the system of the trunk regulators assumes a steady state faster and restores the transmission level to its normal value within $\pm \Delta = \pm\ 0.05$ nep.

It is interesting to note that whenever the speed of regulation increases by an amount that is equal for all regulators, the amplitude of the overregulation at the output of each amplifier remains constant if the level is suddenly changed in one of the line sections; all that occurs is a shift in the curve showing the level restoration.

Methods of Eliminating Overregulation

The undesirable appearance of overregulation in the restoration of a sharply changing transmission level can only be completely eliminated by using independent sources of control current and separate regulation for each of the repeater sections. However, this still involves considerable difficulties and is a measure that is not economically justified.

Of great interest is the possibility of reducing the duration of the level oscillations and reducing the value of the overregulation amplitude by increasing the speed of regulation of the transmission level using the last regulator in the trunk, whereby the speed must not exceed 0.08 nep per second or else the regulation will affect the operation of the tonal telegraph. In this case the last regulator will become the principal regulator, which maintains the residual attenuation stable, and the function of the intermediate regulators reduces to preventing large changes in the level and preventing the increased transmission levels from overloading the line amplifiers of the intermediate stations.

The regulators of the trunk line are kept from becoming energized in the case of short-time level oscillations by the fact that the sensitivity threshold of the polarized relays of the ARU devices in the type 12-channel V-12 system is ± 0.05 nep, and by the fact that there is a time lag in the operation of the regulators whenever the drive is switched and there is a time lag in the start of operation of the regulator; these measures make the quality of the communication channels quite satisfactory whenever the level "jumps" to within ± 0.5 nep from the nominal value of the control-frequency current level.

The ARU devices at each station remain switched on during the operation of the terminal and intermediate repeater stations of the type 12-channel V-12 system. Under unfavorable weather conditions (wet snow or glazed frost) it is necessary to turn on the terminal receiver stations supplementary equalizers which have a large slope of attenuation frequency characteristic and which jointly with the regulating amplifiers of the ARU installations somewhat increase the speed of regulation as compared with the regulators of the intermediate stations, thereby reducing the oscillation time of the residual attenuation of the communication channels.

Of great importance in preventing the effects of overregulation from affecting the quality of high-frequency transmission is the regular performance of electric inspections and adjustments of the control-channel receivers of the ARU, such as the tuning of receiver networks to the precise control frequency, the adjusting of the normal sensitivity of the receivers, the checking of frequency characteristics, sensitivity, and also the checking and lubricating of wearing portions of the electric drive in the ARU installations. These adjustments must be made at least 2 to 3 times a year. There are times when the electric motors of the ARU devices operate normally, but the mechanical coupling between the electric-drive shafts and the shafts of the capacitors of the artificial lines is damaged owing to slippage of the coupling clutch. As a result the ARU are in effect inoperative, and have an adverse effect on the restoration of the disturbed transmission level, as does short-period switching of the regulator on the part of the technical personnel.

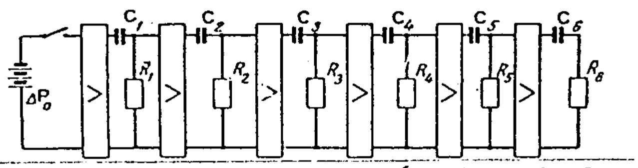

Figure 1. Equivalent diagram of line with 6 automatic level regulators.

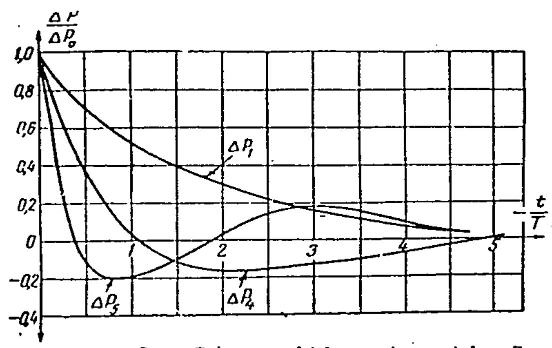

Figure 2. Regulation curves for line with automatic level regulators in which the speed of regulation follows an exponential curve.

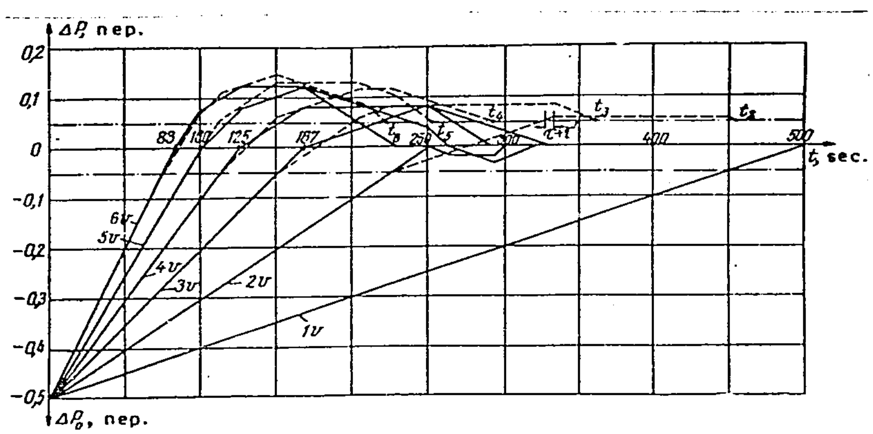

Figure 3. Dynamics of the process of level restoration in an aerial line with 6 automatic level regulators at $\nu = 0.001$ nep/second, $\Delta = \pm 0.5$ nep, $\tau' =$ one second, and $\tau = 2$ seconds (solid lines represent the process of level restoration without taking the quantities Δ, τ, and τ' into account).

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